ENGINEERING PEER REVIEW

SUPPLEMENTAL TECHNOLOGY STANDARDS OF COMPARISON (STSOC) ANALYSIS for SUBMERGED AQUATIC MACROPHYTE / LIMEROCK STORMWATER TREATMENT AREA (SAV/LR)

Prepared for

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1 BACKGROUND

Florida's 1994 Everglades Forever Act (F.S. 373.4592) and the federal Everglades Settlement Agreement (Case No. 88-1886-CIV-HOEVELER) establish both interim and long-term water quality goals designed to restore and protect the Everglades Protection Area (EPA). As defined in the Act and the Settlement Agreement, the Everglades Protection Area includes Water Conservation Areas 1, 2A, 2B, 3A, 3B, the Arthur R. Marshall Loxahatchee National Wildlife Refuge, and the Everglades National Park.

Activities are currently underway to meet the interim goal of reducing phosphorus levels in discharges from the Everglades Agricultural Area (EAA) and other sources to the Everglades Protection Area to a long-term annual flow-weighted mean concentration of 50 parts per billion (ppb). These activities include the implementation of Everglades Agricultural Area Best Management Practices (BMPs) and the construction of over 42,000 acres of Stormwater Treatment Areas (STAs) through the Everglades Construction Project (ECP). Concurrent with implementation of the ECP, the District is implementing the Everglades Stormwater Program (ESP) to address the water quality issues associated with discharges from the remaining non-ECP Everglades tributary basins. Also concurrent with these activities, the District and other groups are conducting water quality research, advanced treatment technology research, ecosystem-wide planning (e.g., the Comprehensive Everglades Restoration Plan, or CERP), and regulatory programs to ensure a sound foundation for science-based decision-making.

1.1 Everglades Phosphorus Reduction

The long-term goal of the Everglades Program restoration effort is to combine point source control, basin-level, and regional solutions in a system-wide approach to ensure that all waters discharged into the Everglades Protection Area meet the numeric phosphorus criterion and other applicable state water quality standards by December 31, 2006.

In accordance with the Act, the EPA total phosphorus (TP) criterion shall be 10 ppb in the event the Florida Department of Environmental Protection (DEP) does not adopt by rule such criterion by December 31, 2003. The Corps of Engineers Permit for the Everglades Construction Project requires "For the purposes of planning, 10 ppb (total phosphorus) shall be used as the design parameter pending adoption of the numeric criterion by the Department of Environmental Protection or Everglades Regulatory Commission."

The District and other parties are engaged in the research and demonstration of Advanced Treatment Technologies (ATTs) that may be used alone or in conjunction with STAs for achieving the long-term water quality goals of the Everglades. Research teams are evaluating the technical, economic and environmental feasibility for basin-scale application.

Eight ATTs are being evaluated:
- Chemical Treatment - Direct Filtration
- Chemical Treatment - High Rate Sedimentation
- Chemical Treatment - Dissolved Air Flotation/Filtration (DAF)
- Chemical Treatment - Microfiltration
- Low Intensity Chemical Dosing of Wetlands (LICD)
- Managed Wetlands
- Submerged Aquatic Vegetation (SAV)/Limerock

- Periphyton-based Stormwater Treatment Areas (PSTAs)

As a result of the research studies conducted during 1998 and 1999, Chemical Treatment – Direct Filtration, Chemical Treatment – Dissolved Air Flotation/Filtration and Low Intensity Chemical Dosing of Wetlands did not achieve the 10 ppb TP goal, and are not considered viable technologies.

1.2 Supplemental Technology Standard of Comparison (STSOC)

To enable the District to provide a scientifically defensible basis for comparative evaluation of the successful technologies, a Supplemental (Advanced) Treatment Technology Standard of Comparison (STSOC) was established. The STSOC provides an approach to comparing the effectiveness of one advanced treatment technology to another. The STSOC has evolved as follows:

PHASE I: Formulate conceptual approach, development of the Contract Guidance Documents
PHASE II: Development of the evaluation methodology and STSOC database
PHASE III: Development of standardized cost information
PHASE IV: Compilation and evaluation of Advanced Treatment Technology data.

In Phase I, Peer Consultants prepared a concept letter report that proposed twelve evaluation concepts and a Contract Guidance Document (PEER Consultants, P.C./Brown and Caldwell, 1998a). This Contract Guidance Document listed the goals and detailed the specific information on sampling, data management protocol, forms, and formats that each of the Advanced Treatment Technology Demonstration Project Research Teams (DPRTs) needed to follow during data collection.

In Phase II, Peer Consultants refined the evaluation concepts into an evaluation methodology consisting of 10 criteria. The evaluation methodology attempts to provide a basis to compare dissimilar technologies. An STSOC database was developed to serve as a repository for storing DPRTs' research data and as a comparative ATT evaluation tool. The evaluation methodology for the data and information collected from the DPRTs consisted of quantitative and qualitative concepts, which are set forth below.

QUANTITATIVE EVALUATION METHOLOLOGY
1) Level of Phosphorus Concentration Reduction
2) Level of Phosphorus Load Reduction
3) Cost-effectiveness
4) Potential toxicity
5) Implementation schedule

QUALITATIVE EVALUATION METHOLOLOGY
1) Uncertainty Assessment of Full Scale Construction, Operations, and Scale-up
2) Operational flexibility
3) Sensitivity to fire, flood, drought and hurricane
4) Level of effort to manage side streams control
5) Other water quality issues

During Phase III, PEER Consultants/Brown and Caldwell developed standardized costing data to serve as the basis for estimating the cost of equipment, land, levees, etc. to be used by each DPRT in developing full-scale treatment facilities. The cost basis will be used with the evaluation guidelines established in previous documents for Phases I and II to make comparisons between the technologies.

During Phase IV, which is scheduled to be completed within the next two years, data from the ATT projects will be compiled, evaluated and compared.

One of the final deliverables from the demonstration project research teams will be a report summarizing the research results, including a conceptual-level layout of a full-scale treatment system designed to treat the flows and phosphorus loads into and out of STA 2 for the period 1979-1988 (Period of Record or POR). Conceptual estimates of capital and annual operation and maintenance costs will be included in this report, as will preliminary implementation schedules.

2 PROJECT OBJECTIVE

Under SFWMD Contract C-E018, Work Order #12, PB Water was tasked with conducting a peer review of the STSOC analysis of the SAV/LR research and demonstration project conducted by DB Environmental.

2.1 Peer Review Document

Peer review was conducted on the following document:

> "Conceptual Designs and Planning Level Cost Estimates for a Full-Scale Submerged Aquatic Macrophyte/Limerock System - Draft Supplemental Technology Standards of Comparison (STSOC) Analysis for Submerged Aquatic Macrophyte/Limerock Technology", prepared for South Florida Water Management District, by DB Environmental, Inc., dated February 22, 2002.

Throughout this peer review, the above document will be referred to as 'SAV STSOC Report'.

The following document was utilized as supplemental information:

> "Submerged Aquatic Macrophyte/Limerock Treatment Technology fro Phosphate Removal Follow-On Study – Draft Final Report, March 8, 2002" prepared by DB Environmental, Inc.

2.2 Work Objectives

The objective of this project is to conduct an independent review of, and provide comments on the design concept presented in the SAV STSOC Report. The review includes the following major components:

1. Assess the validity of the conceptual design of full-scale facilities;
2. Review of the design assumptions; and

3. Verify that the design is conceptually correct and that there are no major errors in the conceptual design.

2.3 Peer Review Scope of Work

PB Water's peer review team evaluated, based on available information, whether the recommended solution(s) in the SAV STSOC Report meet the intended use and performance goals. The team strived to review the document with regard to the following:

- Review the various design criteria, design assumptions, and technical approaches used by the designers and determine their appropriateness.
- Review the results of field and laboratory investigations during the demonstration stage, the facts and reasoning leading to the opinions, judgments, conclusions, and recommendations in the reports.
- Check for innovations, unproven technology, or untested materials. Study the design team's inquiries or research.
- Check that the design accounted for site-specific features of previous or adjacent construction, available utilities, proposed changes in utilities or access for transportation and other project requirements, and that is otherwise feasible.
- Check that appropriate design standards have been used as the basis for design.
- Check the calculations used in sizing the various basins and estimating their hydraulic characteristics, including seepage (where applicable).
- Check whether models adequately illustrate the flow through the facilities.
- Assess the validity of the assumed biological and ecological characteristics of the full-scale treatment facilities, including interior treatment and discharge quality (where applicable).
- The Consultant(s) shall review all design assumptions, and computations documented in the Standards of Comparison Report and provide peer review comments to the District.

3 PEER REVIEW TEAM

The peer review team was selected based on expertise in the general fields of ecology, wetland engineering, and natural system modeling. The team members were chosen by the SFWMD because of their knowledge and experience in the fields most closely related to biological treatment systems. The follow is a short summary of the peer review team.

ALEXANDER J. HORNE, Ph.D.
Dr. Horne has been the professor of Ecological Engineering at the Department of Civil & Environmental Engineering at the University of California since 1971. He is an expert in biological and chemical aspects of water and aquatic management including pollution in lakes, reservoirs, wetlands, rivers, streams, estuaries and the open ocean. He has studied lakes, reservoirs, streams, wetlands and oceans in Africa, Antarctica, Alaska, Europe, Australia, Asia, North and South America. He has been principal investigator in over 50 research projects and acted as a major consultant or advisor in over 300 water-related projects. Dr. Horne has 190+ publications in major scientific and engineering journals & reports including the most popular textbook on *Limnology* (the study of lakes, ponds, reservoirs, wetlands, rivers, streams, and estuaries).
Ph.D. 1969 - University of Dundee, Scotland: Limnology & Oceanography.
B.Sc. 1964 - University of Bristol, England: Biochemistry (Chemistry & Zoology options).

BIJAY K. PANIGRAHI, Ph.D., P.E., P.G.

Dr. Panigrahi has more than 20 years of experience in the specialty areas of hydrologic modeling, ground water modeling, statistical analyses, geohydrology and water resources engineering, including hydraulics, water quality assessment and modeling, monitoring network and water resources facility design. Dr. Panigrahi is an expert in model development and implementation. He has extensive knowledge in statistical evaluation of hydro-environmental data, including water quality, flow, and hydrometeorological records of both surface and ground water systems. Dr. Panigrahi has developed more than half a dozen models, has authored many publications and spoke many times at internationally recognized events in the water resources field.

Ph.D. Civil Engineering, Drexel University, USA, 1985

M.S. Civil Engineering & Geology, Oklahoma State University, USA, 1981

M.E. Hydraulics Engineering, Asian Institute of Technology, Thailand, 1978

B.S. Agricultural Engineering, Orissa University of Ag. & Tech., India, 1976

ARNOLD G. VAN DER VALK, Ph.D.

Dr. Van Der Valk has been Director of Iowa Lakeside Laboratory since 1994, and has been Professor in the Department of Botany at Iowa State University since 1982. Over the last 20 years, Dr. Van Der Valk has participated in and led scientific research around the world, and has taught in Ecology and Botany Programs at universities in South America, Europe and Australia. He teaches senior-level undergraduate course in plant ecology and graduate courses in wetland ecology, restoration ecology, population ecology, and community ecology. Here in Florida Dr. Van Der Valk was recently a Visiting Eminent Scholar at the Florida Center for Environmental Studies in Palm Beach Gardens. Additionally, he is author or co-author of five books and close to one hundred wetland and ecology related publications.

B.Sc. 1968 - University of Windsor, Canada: Biology

M.Sc. 1970 - University of Alberta, Canada: Botany (Plant Ecology)

Ph.D. 1973 - N.C. State University: Botany (Plant Ecology)

4 PEER REVIEW

The research that has been done on the Submerged Aquatic Vegetation/Limerock (SAV/LR) treatment systems by DB Environmental (DBE) and by the South Florida Water Management District (SFWMD) has been extensive and has addressed many of the critical 'why' and 'how' questions that needed to be answered in order to evaluate the validity of the concept and to design a full-scale facility. Because of the work done on the biogeochemistry of phosphorus (P) in SAV systems, the hydraulics of a full-scale system (STA-1W Cell 4), and vegetation of SAVs, we know submersed aquatic vegetation can be established and maintained, the basic mechanisms of P removal and storage, and the potential hydraulic problems in SAVs caused by internal canals. The attention paid in these studies to the significance of species of P: Total P (TP), Soluble Reactive P (SRP), Dissolved Organic P (DOP), and Particulate P (PP)) in influents and effluents is particularly noteworthy. This has greatly improved our understanding of how SAVs function with regard to P removal and how their efficiency could potentially be improved.

4.1 Level of Phosphorus Concentration Reduction

Mean TP in the outflows of NTC-15, STC-9 and Cell 4 for the calibration period were 23, 21, and 20 ppb, respectively. During the verification period, they were 34, 20 and 19 ppb, respectively. For the first six years of its operation, the mean TP in the outflow of Cell 4 was 22 ppb. Cell 4 was poor at TP removal during the first two years of operation. When considered in their entirety, the data collected from test cells and STA-1W Cell 4 indicate that for SAV systems the TP long-term concentration in the outflows will most likely be around 20 ppb or higher. This convergence toward an outflow TP concentration of around 20 ppb is relevant when considering that the mean TP concentrations in the inflows varied considerably (35 to 112 ppb) as did the size of the units and their hydraulic loading rates.

Nearly all of the P in the outflows was in the form of DOP and PP, and the effectiveness of SAV treatment systems for TP reduction is primarily due to their limited ability to reduce DOP and PP levels. How much SAV treatment systems can lower TP depends primarily on how much influent DOP and PP is removed and how much DOP and PP is produced internally. Mean DOP concentrations in the effluents from the test cells and Cell 4 range from 8 to 13 ppb, but are mostly less than 10 ppb. Mean PP concentrations in the effluents are more variable and range from 5 to 18 ppb but seem to be mostly around 11 or 12 ppb. SRP in effluents is generally around 2 ppb. In summary, the TP in the effluent of an STA is most likely to consist of about 10 ppb of DOP, 10 ppb of PP, and 2 ppb of SRP.

4.1.1 Conceptual Design of Full-Scale SAV/LR Facilities

The SAV system was tested in two ways; in microcosms and mesocosms and in the large vegetated SAV Cell 4 in STA-1W (360 acres). In the cosms, control of the vegetation to promote a dominance of SAV was carried out on a couple of occasions. In Cell 4, no attempt was made to control SAV and competition (shading) with floating macrophyte vegetation (principally water hyacinth) and probably scouring of the SAV by drifting emergent vegetation occurred during windy periods. Most importantly, the hydraulic flow in cell 4 was poorly designed for nutrient removal since active short-circuiting occurred from the inflow to the outflow. Thus the test conditions were better than for PSTA due to the presence of the large SAV dominated Cell 4, but far from ideal and different from a full-scale design.

The SAV STSOC Report and the data it contains indicate that SAVs *per se* were not able to reduce TP in the effluent of SAVs to a concentration of 10 ppb for any prolonged period of time. At best, they might be able to reach 14 ppb under some conditions, but more likely, TP levels in SAV effluents will be around 20 ppb or more when operated under real-world conditions (fluctuating water levels, prolonged periodic droughts, herbivory from coots and other animals, hurricanes). That limestone berms will actually reduce TP levels further needs to be demonstrated under real world conditions. Even if the limestone berms reduce PP levels to 0 ppb, which is unlikely, TP concentrations in effluents will probably still be above 10 ppb much of the time because of residual SRP (approximately 2 ppb) and DOP (approximately 10 ppb).

The conceptual design of the full-scale SAV facilities is based on the assumption that:

a) The influent concentration of 122 ppb will be reduced to effluent concentrations of 20 and 26 ppb for Post-BMP water; and
b) The influent concentration of 50 ppb will be reduced to 14 and 20 ppb for Post-STA water.

Based on the experimental data from NTC-15 (Table 3-2), the effluent concentration of 26 ppb is achievable for Post-BMP water if SAV is combined with limerock berm, otherwise the effluent concentration is likely to be significantly higher. The reduction of influent concentration to an effluent value of 20 ppb is unsupported. The experimental data for Cell 4 (Table 3-3) indicate that the effluent concentration of 20 ppb is achievable for Post-STA water. The measurements from the calibration period indicate that a lower effluent concentration of 14 ppb is periodically attainable, however the sustainability is questionable.

4.1.2 Design Assumptions

The design assumptions made in the SAV experiments were appropriate for the stated task. The assumption that SAV can become a dominant (in terms of nutrient removal at least) in the STA conditions was made and was demonstrated to be valid. In addition, the planting of some SAV species was shown to be possible.

A major design requirement for wetlands is that there is plug flow, either in each cell or with sufficient cells in series. This assumption was met in the cosms but not in Cell 4. Since much of the analysis was based on Cell 4 due to its large size and greater applicability to the full-scale task, this design assumption was not well met.

A third design assumption was that depth was not an important regulator of TP removal. At present there is mixed evidence on the effect of depth on the removal of several pollutants. In the full-scale SAV system, large variation in depth will occur during dry and wet periods. The assumption of no effect was verified for a reasonable range of depths.

Perhaps the most important design assumption was that the TP removed would be immobilized in a biologically unavailable form. DBE and their team did a good job in carrying out the chemistry needed to find some answers to this design assumption.

The lowest for a longer period attainable effluent concentration based on Cell 4 calibration data is 14 ppb. This was the “lower limit” or target TP mean concentration in outflows in Post-STA model simulations. Along with various assumptions about hydraulic efficiency (i.e., number of tanks in series), it was used to estimate the area needed for an SAV treatment system. Why TP effluent concentrations during the Cell 4 calibration period were lower than before and after it needs to be carefully examined. Were DOP levels lower during the calibration period? Were PP levels lower? Data on DOP and PP concentrations in influent and effluent from Cell 4 during the calibration period and before and after it are not given in the SAV STSOC Report. They should be added in summary form, as they are for NTC-15 and STC-9 for their calibrations periods. There was a drought during much of the calibration period. How did this affect input and output levels of TP, SRP, DOP and PP?

The conceptual model developed (PMSAV) does contain a mechanism (sedimentation) for PP removal, but it essentially ignores DOP removal and production. There is also no mechanism for internal PP production (e.g., algal production, litter decomposition). The numerous pathways for moving dissolved and particulate P from the accumulating sediments back into the water column are all lumped into a single "recycle" pathway. The inclusion of various species of P in the PMSAV model would result in a more accurate P removal model, especially given the central importance of DOP and PP for understanding SAV TP removal. As noted in SAV STSOC Report, however, it is not feasible to construct such a model because of the lack of available data needed to calibrate it. This unavoidable shortcoming in the current PMSAV model reduces the reliability of this model for predicting the behavior of SAV systems, especially under various conditions that will alter internal SRP, DOP and PP production rates (e.g., algal blooms, herbivory, high winds, herbicide applications) and export.

Improving the performance of SAVs for TP removal will require finding some practical way to reduce DOP and PP levels. This is recognized in the SAV STSOC Report and one promising way to do this, limestone berms, has been investigated. Limestone berms seem to trap PP and convert it to SRP, which is then quickly removed. The berms, however, have only a minor effect on DOP levels. Even if the berms can remove most of the PP, it is likely that TP levels in the effluent may still exceed 10 ppb much of the time.

4.1.3 Validity of the Conceptual Design

The concept that SAV could reliably remove TP down to about 20 ppb was validated. Lower TP values, specifically 10 ppb, were not validated on a steady basis. The ability of the SAV to maintain a population that could reliably remove TP was proven.

As configured, an effluent concentration maximum of 10 ppb was not met by any of the SAV facilities except occasionally. The SAV method cannot meet the 10 ppb TP requirement. From the data presented in the reports and at the February 2002 meeting, the SAV has an apparent threshold of TP removal at about 20-25 ppb that cannot be lowered without changing the kind of system to be used.

Although not specifically stated in the design assumptions, the experiments showed the very important finding that the kind of SAV did not appear to affect the effluent TP concentrations. *Hydrilla* was an exception because its invasion of Cell 4 occurred late in the test, and therefore it was not tested.

The shortcomings of the PMSAV model, however, do not invalidate its use for modeling of the required size of an SAV footprint. The model was used to estimate the area needed with different levels of hydraulic mixing to get a final effluent concentration of "greater than or equal to 14 ppb." The data available suggest that TP concentrations in the effluents from an SAV system designed using this model (or any other model) will likely be "greater", i.e., approximately 20 ppb, than the "lower limit" used to calibrate the model much of the time.

The aspects related to the total phosphorus concentration in the conceptual design are valid within the specified limitations as indicated in the report.

Recommendations:

The lowest for a longer period attainable effluent concentration based on Cell 4 calibration data is 14 ppb. This was the “lower limit” or target TP mean concentration in outflows in Post-STA model simulations. Why TP effluent concentrations during the Cell 4 calibration period were lower than before and after it needs to be carefully examined. This is important as the 14 ppb may underestimate the effluent TP level from SAVs. Further, it is recommended that additional research be done to determine the effectiveness of limestone berms in relation to the removal of different P-species.

Regarding PMSAV modeling, the inclusion of various species of P in the PMSAV model would result in a more accurate P removal model, especially given the central importance of DOP and PP for understanding SAV TP removal.

4.2 Total Phosphorus Load Reduction

4.2.1 Conceptual Design of Full-Scale SAV/LR Facilities

The concept was that greater TP removal could be achieved overall by reducing the hydraulic residence time (or increasing hydraulic loading). The drawback is that the concentration of TP would rise under these conditions.

The total phosphorus loading removed from NTC-15 for Post-BMP water ranged from 64% during the calibration period to 69% during the verification period. For Post-STA water, the loading rates were 73% and 62% for the calibration and verification periods, respectively. In general, this is consistent with the design assumptions with a TIS value of 2 for the Post-BMP and 1 for the Post-STA conditions.

4.2.2 Design Assumptions

Tests show that a higher TP concentration in the outflow would result from higher loading, but greater overall TP removal would occur.

The modeling (including calibration) was based on the assumption that the Post-BMP system reaches a steady-state condition (from the SAV standpoint) and ignores the initial startup period. Based on the pre-existing condition of NTC-15, long-term life of the full-scale design and considering the simplified assumptions of PMSAV, this assumption is appropriate for both the calibration and full-scale design conditions.

4.2.3 Validity of the Conceptual Design

The concept of a tradeoff between TP loading decreasing with increased flow was validated. The penalty that TP concentration increased under higher loadings was also validated. The conceptual design, from the standpoint of total phosphorus load reduction, seems valid for preliminary full-scale design analysis.

4.3 Compliance with Water Quality Criteria

4.3.1 Conceptual Design of Full-Scale SAV/LR Facilities

The design to determine other effects such as toxicity and long-term sustainability of the SAV system was to monitor other components including mercury and toxicity by selected EPA-approved tests. This methodology is adequate given the nature of the runoff and its modification by the upstream cattail wetlands. Monitoring was simple in that complex ecosystem effects were not measured, but were appropriate for the nature of the expected effects on non-target organisms.

As documented in the SAV STSOC Report, there do not seem to be serious water quality problems (e.g., high mercury concentrations) associated with the effluents of SAVs. The two problem water quality parameters, oxygen and pH, associated with SAV effluents both fluctuate significantly on a daily basis in any aquatic system in which photosynthesis is occurring. Discharging effluent from an SAV with oxygen or pH levels periodically above or below the permitted means should not cause any significant degradation to the water into which it is discharged.

4.3.2 Design Assumptions

It was assumed that the toxicity to *Ceriodaphnia* was a good general measure of toxicity of the effluent. The zooplankton *Ceriodaphnia* is an uncommon planktonic species and not likely to be an important member of the Everglades biota, which will be dominated by benthic organisms. However, *Ceriodaphnia* was chosen by the EPA for toxicity testing primarily due to its sensitivity to some forms of heavy metals and its ability to survive the rigors of laboratory testing. It should be noted that heavy metals have not been implicated as a problem in the Everglades region and are unlikely to be so due to the high dissolved organic carbon (DOC) which chelates the toxic ionic metal fractions. The methods devised for testing toxicity by the EPA using *Ceriodaphnia* are not ideal for an Everglades application, but have the advantage that the agency accepts the results.

4.3.3 Validity of the Conceptual Design

The conceptual design was validated in terms of toxicity. The occasional finding of toxicity is typical with the *Ceriodaphnia* test and probably stems from the incomplete life cycle analysis.

Recommendations:

A more complete monitoring program using a wider range of indigenous biota should form part of the full-scale operations. Further, the DO level below 5 ppb may need a water quality variance.

4.4 Cost Effectiveness of the SAV/LR Technology

4.4.1 Conceptual Design of Full-Scale SAV/LR Facilities

STSOC (Post-BMP) Conceptual SAV/LR Facility Design
Table 4-12 presents the Post-BMP design criteria summary. This table is not completely filled out. The information should be completed even if the model predicted footprint fits within the STA-2 footprint. Figure 4-14 presents the levees and canals as part of the full-scale SAV system without limerock berms. The capital/construction cost and operating cost for these features are not included in Table 4-15. In addition, costs for the replacement items as indicated by Table 4-14 do not seem to be incorporated in Table 4-15. Therefore, the cost factors summarized in this table do not represent the anticipated construction cost. Thus, the present worth cost per pound TP removed in Table 4-16 may be underestimated.

Can the surplus area of approximately 2,000 acres (after Post-BMP footprint) be used to partially meet the requirement for Post-STA land acquisition? If so, the capital cost for Post-STA can be significantly reduced. Therefore, Tables 4-19 and 4-20 should be revised, if appropriate.

Optimum Conceptual SAV/LR Facility Design
Table 4-21 presents the Optimum design criteria summary. This table is not completely filled out. The information should be completed even if the model predicted footprint fits within the STA-2 footprint. This scenario considers Post-BMP TIS of 5 and Post-STA TIS of 2. This scenario includes limerock berms, but limerock berm estimates are entered as zero values in Table 4-22. Does this mean the capital/construction cost and operating cost for these features are not included in Table 4-24? In addition, costs for the replacement items as indicated by Table 4-23 do not seem to be incorporated in Table 4-24. Therefore, the cost factors summarized in this table do not represent the anticipated construction cost. Thus, the present worth cost per pound TP removed in Table 4-16 may be underestimated.

4.4.2 Design Assumptions

The design assumptions related to the SAV technology appear acceptable for the STSOC SAV/LR Conceptual design. However, the assumptions for the Optimum SAV/LR Conceptual Design need more support with regard to the chosen TIS factor of 5 for the Post-BMP, and TIS factor of 2 for the Post-STA scenarios.

4.4.3 Validity of the Conceptual Design

The conceptual design relevant to the SAV technology for both the STSOC and Optimum scenarios seem appropriate.

Recommendations:

The engineering assumptions for the cost estimate should be reviewed, and modified as appropriate. In addition, further details regarding the cost estimate and quantity estimate should be documented in the report such that the cost per pound TP removed can be independently verified.

4.5 Implementation Schedule

4.5.1 Conceptual Design of Full-Scale SAV/LR Facilities

The SAV STSOC Report anticipates that the SAV/LR technology will reach an apparent steady-state condition (post startup condition) in 1 to 3 years after construction of the system is complete. Based on the conditions experienced in NTC-15 and Cell-4, this is attainable.

Implementation of a full-scale SAV/LR facility requires engineering design, selection of construction methods, and procurement, as well as for permitting and environmental impact analysis (EIA). The SAV implementation schedule provides two months for design and method selection, which does not seem adequate for these efforts. There is no time allotted for permitting and EIA, which does not seem correct.

4.5.2 Validity of the Conceptual Design

An implementation schedule could be based on the conceptual design based on the SAV results. The cosm SAV grew rapidly and despite the differences in the species of plant, the TP removal quickly (months) reached its best TP removal performance. The performance of Cell 4 with its poor hydraulics and natural cattail island scouring showed that sustained performance in TP removal is possible.

Recommendations:

Adequate time for SAV engineering design, construction method selection, and procurement efforts, as well as for permitting and an environmental impact analysis should be reflected in the implementation schedule.

4.6 Feasibility and Functionality of the Full-Scale Design

4.6.1 Conceptual Design of Full-Scale SAV/LR Facilities

The successful establishment of an SAV in Cell 4 demonstrates that it is feasible to build such a system at the field scale. The lessons learned from dealing with internal hydraulic problems in Cell 4 will be useful for designing future SAVs so that short-circuiting is minimized. In other words, designing and building full-sale SAVs should not pose any major engineering or construction problems. The use of limestone berms to improve internal hydraulic efficiency and to reduce PP in the effluents needs additional study to verify that both would happen under real-world conditions.

There are some lingering questions about the long-term stability of the plant communities in the SAVs, especially about the effects of the invasion of SAVs by *Hydrilla*. There is no reason to believe that a *Hydrilla*-dominated community will be significantly less efficient at removing TP than one dominated by other species. This, however, needs to be confirmed as is recommended in the SAV STSOC Report. In any case, *Hydrilla* abundance could be controlled in an SAV with herbicides. It is also likely that control of cattails and possibly free-floating plants (e.g., water hyacinth, water lettuce) will be needed in SAVs on a regular basis. The effects of plant control practices on SRP, PP and DOP production are not considered in the current PMSAV model.

The limestone berms that are proposed to reduce PP in effluents will be quickly colonized by trees, e.g. willows and wax myrtle. In effect, these berms are the equivalents of the limestone heads or cores of fixed tree islands in the Everglades. Whether trees should be allowed to become established or not needs to be carefully considered. Allowing trees to become established could be beneficial in several ways, including stabilizing the berms and taking up and sequestering P from water passing through the berms. Birds would eventually begin to roost in the trees and this would eventually result in the concentration of P on the berms as they gradually turn into tree islands. This could actually improve the efficiency of the SAVs as nutrient sinks.

The height of the perimeter berm of the STA-2 is approximately 4 feet. The inflow hydrograph for the Post-BMP should be routed through the storage area to determine the minimum height required to contain the design flow. Only then should the height of the limerock berm be specified.

The conceptual design proposes 3.5 feet high limerock berms placed perpendicular to flow leaving only 0.5 foot for the entire flow to pass over. This constricts the flow from a hydraulic perspective. A number of adverse conditions could take place when the flow is constricted from 4 feet of opening to 0.5 foot, including a) overtopping of banks during peak flow creating flood nuisance, b) threatening of the structural integrity of the perimeter berms if frequent overtopping persists, and c) development of scouring at the toe of the limerock berms during high flow conditions.

Further, the proposed limerock berms are wide (26 feet at the base) and are placed on muck. This may create adverse conditions for structural integrity of the berms. Settlement of the berm could create buckling and preferential flow through ‘pipes’ across the berm, which could reduce treatment efficiency.

4.6.2 Design Assumptions

The main design assumption was that Cell 4 within the STA-2 footprint would be a good guide to how the mature full-scale SAV system would behave, which seems a valid assumption. Taken together with the cosm and research efforts on P-immobilization, the design provided good information about the potential needs for the full-scale system.

4.6.3 Validity of the Conceptual Design

The Cell 4 test showed that the TP removal process to the best effluent values of about 20 ppb cannot be achieved at full-scale and on a consistent basis unless the hydraulics are such that a true plug flow is achieved. Plug flow can be achieved by making sure there is no short-circuiting, as was clearly demonstrated by the dye tests in Cell 4. However, it is possible to simulate plug flow by adding about 6 cells in series, or by constructing baffles and barriers as was proposed.

Recommendations:

The full-scale system can be designed based on the results from the SAV test cosms and Cell 4. It is recommended that detailed attention be paid to the hydraulics of the full-scale cells to ensure plug flow if possible within the cells. In addition, several cells in series should be used.

Note that the cells in series should accompany several trains of cells in parallel to allow management of all the eventualities expected in the natural system (floods, droughts, fire, hurricanes).

The inflow hydrograph for the Post-BMP should be routed through the storage area to determine the minimum height required to contain the design flow.

The construction methods of the limerock berms as proposed in this document may need to be revisited in terms of their structural integrity. Additionally, berm height and its effects on flow, erosion, and the creation of preferential flow paths through the berms should be further assessed.

The engineering assumptions of the conceptual design should be re-addressed. Documentation on the engineering feasibility should be referred to or included. Limitations of the presented conceptual design should be clearly documented in the SAV STSOC Report. It is recommend this be a separate subsection in the SAV STSOC Report so that it provides a clear understanding of the limitations of the engineering feasibility for the proposed conceptual design.

Future research should address the long-term stability of the plant communities in the SAVs, especially about the effects of the invasion of SAVs by, for example, *Hydrilla*. Research should determine the effects of invasion on P-removal capacities of SAVs. In the case where P-removal would be reduced by the invasion of, for example *Hydrilla* or cattails, a means of controlling this vegetation should be developed and quantified.

Additionally, future research should address the colonization of the proposed limestone berms with trees, and its effect on SAV/LR system P-removal performance.

4.7 Operational Flexibility

4.7.1 Conceptual Design of Full-Scale SAV/LR Facilities

The conceptual design for the management of the full-scale systems for floods, droughts and fire was tested using drawdown and drying cycles that approximated the normal (non-drought) periods. The tests measured the reduction in volume (vegetation depth in the cosms) during a few months of drying (droughts), and simulated floods by approximately doubling the water level in the SAV. No fire or hurricane tests were performed.

Both prolonged droughts and prolonged floods could significantly reduce the effectiveness of SAVs as P sinks. The drought because of P releases from sediments when SAVs are reflooded. The flooding because of shortened hydraulic residence times and faster currents that increase the likelihood of SRP, DOP and PP moving out of the SAVs. Short-circuiting could also occur during these high flow and high water periods.

4.7.2 Design Assumptions

The assumption was that SAV would not be seriously affected by drying because droughts are normal for this kind of vegetation. Further, it was assumed that a few months of allowing water to evaporate in a cosm would be equivalent to natural drying. The assumption was that TP removal by SAV would not be seriously affected by flooding or drying since these events are a normal part of the cycle for this kind of vegetation. The assumptions were that a few months of allowing water to evaporate in a cosm would be equivalent to natural drying and a few weeks of flooding would be equivalent to the flooding expected in the full-scale system.

4.7.3 Validity of the Conceptual Design

The drying and flooding experiments showed a satisfactory response. The first components of a mature SAV grew quickly (few weeks) and TP removal was restored (given that the inflow was much increased over the pre-drawdown period). Similar removals to the pre-drawdown values for TP were then reached within two months, despite the higher loading rates.

Fire and hurricanes were not tested. Fire should have similar effects to drawdown for these plants and re-growth should not be any longer than the tested drawdown (two months).

Recommendations:

The full-scale operation will require a few weeks to a few months after droughts or fires before complete TP removal resumes. Thus the water will need to be held for up to two months before it can be released with the expected best removal rates given TP in the effluent at 15-25 ppb. Therefore it is recommended that at least one set of parallel cells be constructed to allow sequenced re-flooding and operation following droughts and/or fire.

The full-scale operation will require a few weeks after natural or artificial drawdown or droughts before TP removal resumes. Thus the water will need to be held for some weeks before it can be released with the expected best removal rates given TP in the effluent at 15-25 ppb. Therefore it is recommended that at least one set of parallel cells be constructed to allow sequenced re-flooding and operation.

Although not tested for specifically, it is not expected that hurricanes will have a direct major impact. However, it is probable that any emergent vegetation in deeper water will be blown about, even if originally anchored by roots. It has been shown in Cell 4 that such movement is detrimental to SAV. Thus is it recommended that the SAV cells not have emergent vegetation or if they do, that it is prevented from moving in floods and hurricanes.

It is important that further study be done on the effects of hurricanes on SAV performance.

4.8 Sidestream Management

4.8.1 Conceptual Design of Full-Scale SAV/LR Facilities

Sidestream management should not be a problem if periodic drawdowns are part of the planned operation of SAVs to consolidate accumulating sediments. The conceptual design for sidestream management in full-scale SAV systems was tested using drawdown and drying cycles that approximated the normal (non-drought) periods. The test for biosolids consisted of measuring the volume reduction (vegetation depth in the cosms). No test was performed on the eventual fate of the peat.

An experiment to control emergent macrophytes (cattails) was carried out using herbicides in the larger mesocosm.

4.8.2 Design Assumptions

The design assumption was that the measured depth and dry shrinking of the peat could be used to determine eventual sludge management techniques. Although not stated, it is reasonable to assume that the known loss rates for peat in the agricultural areas can be used to assist in sludge management.

The design assumption was that emergent macrophytes could be controlled and that other SAV plants would then thrive in the open spaces.

4.8.3 Validity of the Conceptual Design

After the dry-out test, the SAV sprang back into full vigor and P-removal in a short time (few weeks) as expected from a pioneer “weed-type” vegetation that grows in seasonal wetlands.

No attempt was made to simulate sludge handling. Emergent plants were killed using pesticides and SAV was successful in colonizing the empty areas. The volume and accumulation of peat was not well documented for the full-scale life of the project using direct data from the tests but could easily be found.

Recommendations:

The volume of sludge buildup in full-scale SAVs should be determined. Then, sludge handling experiments, primarily drying and perhaps burning should be performed to assist in estimating the type and frequency of management needed to prevent the SAV wetlands from becoming dry land by filling in with peat.

Additionally, attention should be paid to how to control macrophytes by other means than herbicides. Mechanical cutting and leaving the cut in place is method successfully used in other treatment wetlands.

5 CONCLUSIONS / RECOMMENDATIONS

The research that has been done on the Submerged Aquatic Vegetation/Limerock (SAV/LR) treatment systems by DB Environmental and by the South Florida Water Management District (SFWMD) has been extensive and has addressed many of the critical ‘why’ and ‘how’ questions that needed to be answered in order to evaluate the validity of the concept and to design a full-scale facility. Because of the work done on the biogeochemistry of phosphorus (P) in SAV systems, the hydraulics of a full-scale system (STA-1W Cell 4), and vegetation of SAVs, we know submersed aquatic vegetation can be established and maintained, the basic mechanisms of P removal and storage, and the potential hydraulic problems in SAVs caused by internal canals. The attention paid in these studies to the significance of species of P: Total P (TP), Soluble Reactive P (SRP), Dissolved Organic P (DOP), and Particulate P (PP)) in influents and effluents is particularly noteworthy. This has greatly improved out understanding of how SAVs function with regard to P removal and of how their efficiency could potentially be improved.

The following issues regarding SAV/LR implementation came forward from the SAV/LR STSOC analysis under this review project.

P-Removal Performance
The major mechanism of P removal in SAV systems appears to be the co-precipitation of P with calcium carbonate that is facilitated by pH in the water column rising above 9 due to photosynthesis. SAVs can significantly reduce TP in either Post-BMP or Post-STA influent water. The SAV was shown by these studies to be a good method of immobilizing TP down to an effluent level of about 20 ppb. The outflow TP concentration remained at the lower levels even if there was a large increase in influent TP (up to 90 ppb). This shows the necessary robustness for the SAV/LR wetland system.

Sustainable P-removal down to an effluent level of 14 ppb as noted in the SAV STSOC Report may be overestimated as TP effluent concentrations during the Cell 4 calibration period were lower than before and after this calibration period. Why this occurred needs to be carefully examined. Were DOP levels lower during the calibration period? Were PP levels lower? Data on DOP and PP concentrations in influent and effluent from Cell 4 during the calibration period and before and after it are not given in the SAV STSOC Report.

At the mesocom and test-cell level, although P removal efficiency improves with increasing hydraulic and TP loading rates, the concentration of total P (TP) in the outflow increases.

Species of P
Nearly all of the P in the outflows was in the form of DOP and PP, and the effectiveness of SAV treatment systems for TP reduction is primarily due to their limited ability to reduce DOP and PP levels. How much SAV treatment systems can lower TP depends primarily on how much influent DOP and PP is removed and how much DOP and PP is produced internally. Generally, the TP in the effluent of an STA is most likely to consist of about 10 ppb of DOP, 10 ppb of PP, and 2 ppb of SRP. Therefore, SAVs *per se* will not reduce TP in their effluents to 10 ppb as they are not able to reduce either effluent DOP or PP levels consistently to less than 10 ppb. The addition of limestone berms to SAVs might be able to reduce PP levels significantly in effluents, but probably not DOP. Consequently, even with limestone berms, SAVs are unlikely to meet the 10 ppb TP proposed standard for discharge. Future research should address the question if there are practical ways to reduce DOP in effluents.

Hydraulics
An important aspect in optimizing SAV performance is hydraulics: ensuring plug flow through the wetland and prevention of short-circuiting. TP removal in Cell 4 was compromised by the short-circuiting of flow within this cell due to the presence of canals along the periphery and within the cell. Short-circuiting can be prevented in wetlands design and must be prevented in the full-scale system.

Species of SAV / Vegetation Control
Long-term stability of the plant communities in the SAVs needs further investigation, especially the effects of the invasion of SAVs by *Hydrilla*. There is no reason to believe that a *Hydrilla*-dominated community will be significantly less efficient at removing TP than one dominated by other species. This, however, needs to be confirmed as is recommended in the SAV STSOC Report. *Hydrilla* abundance could be controlled in an SAV with herbicides. It is also likely that

control of cattails and possibly free-floating plants (e.g. water hyacinth, water lettuce) will be needed in SAVs on a regular basis. The effects of plant control practices on SRP, PP and DOP production are not considered in the current PMSAV model.

The plant palette does not seem to be too important here for TP removal. This is unexpected since the plant species does matter in the removal of other pollutants such as nitrate or pesticides. Therefore, this section of the work should be carefully examined to see if different plants really were the same in terms of TP removal. The data should be reexamined to determine if plant species is a factor.

Limestone Berms

The limestone berms that are proposed to reduce PP in effluents may be quickly colonized by trees. Whether trees should be allowed to become established or not needs to be carefully considered. Allowing trees to become established could be beneficial in several ways, including stabilizing the berms and taking up and sequestering P from the water passing through the berms. Birds would eventually begin to roost in the trees, and this would eventually result in the concentration of P on the berms as they gradually turn into tree islands. This could improve the efficiency of the SAVs as nutrient sinks. Future SAV research should address the question if limestone berms improve hydraulic mixing and significantly increase the removal of PP.

Other Water Quality Aspects

SAV/LR effluent is not expected to be toxic to down-stream flora or fauna. However, a more complete monitoring program using a wider range of indigenous biota should be part of the full-scale operations. Further, the dissolved oxygen level below 5 ppb may need a water quality variance, but is not expected to have an adverse impact on Everglades flora and fauna.

Operational Flexibility

The drying and flooding experiments showed a satisfactory response. The first components of a mature SAV grew quickly (few weeks) and TP removal was restored soon thereafter. The full-scale operation will require a few weeks to a few months after droughts or fires before complete TP removal resumes. Thus the water will need to be held before it can be released with the expected best removal rates given TP in the effluent at 15-25 ppb. Therefore, it is recommended that at least one set of parallel cells be constructed to allow sequenced re-flooding and operation following droughts and/or fire.

Future research should include the following: How much will highly pulsed loadings, prolonged droughts, and uprooting (hurricanes) reduce the TP removal efficiency of SAVs? What affect will increasingly large animal populations e.g. alligators, fish, birds, etc., in SAVs and on limestone berms have on P cycling, especially on PP and TP levels in effluents?

Sidestream Management

SAV systems will have a buildup of biosludge, and invading macrophytes will need to be managed. It is recommended that the volume of sludge buildup in full-scale SAVs be determined more accurately. Then, sludge handling experiments, primarily drying and perhaps burning, should be tested to assist in estimating type and frequency of management needed to prevent the SAV wetlands from becoming dry land by filling in with peat. Further research may also be done on to how to control macrophytes by other means than herbicides. Mechanical cutting and leaving the cut in place is method successfully used in other treatment wetlands.

Cost Estimates

The engineering assumptions for the cost estimation should be reviewed, and further details regarding the cost estimate and quantity estimate should be documented in the report such that the cost per pound TP removed can be verified. Limerock berm estimates are entered as zero values in listed tables. Does this mean the capital/construction cost and operating cost for these features are not included? Additionally, costs for the replacement items as indicated by the SFWMD do not seem to be incorporated. Thus, the present worth cost per pound TP removed may be underestimated.